Acute normovolemic hemodilution and intraoperative cell salvage in aortic surgery

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Objective: **The objective of this study was to report current transfusion requirements and outcomes in patients undergoing elective aortic surgery with autologous transfusion.**
Methods: **This was a retrospective review of transfusion practice in infrarenal aortic surgery in a tertiary vascular unit with a longstanding interest in autologous transfusion. One hundred and ten consecutive patients underwent infrarenal aortic surgery with a combination of acute normovolemic hemodilution (ANH) and intraoperative cell salvage (ICS). All patients underwent hemodilution to a target hemoglobin concentration of 11 g/dL and underwent ICS with a centrifugal device.**
Results: **Median blood loss was 1140 mL (interquartile range [IQR], 683 to 1609 mL) in 78 aneurysm repairs and 775 mL (IQR, 400 to 1225 mL) in 32 aortobifemoral bypasses for occlusive disease ($P = .02$), resulting in a median salvaged red cell volume of 403 mL (IQR, 256 to 563 mL) for aneurysm repairs and 250 mL (IQR, 200 to 290 mL) in bypass surgery ($P = .001$). Thirty-six patients (33%) needed transfusion of stored blood, for a total of 115 units, with just four patients needing more than five units. The mortality rate was 8% (9/110). With multivariate analysis, low hemoglobin level ($P = .006$) and low platelet count ($P = .023$) were associated with stored blood transfusion.**
Conclusion: **Blood loss is too small to justify ICS in surgery for occlusive disease; ANH alone may be a suitable strategy. With appropriate experience, the combination of ANH and ICS may render crossmatching unnecessary, even in aortic aneurysm surgery. (J Vasc Surg 2002;36:31-4.)**

Autologous transfusion is becoming increasingly popular in blood conservation strategies and, in Britain, has been prioritized by the National Health Service.[1] Because aortic surgery is associated with significant blood loss, the use of autologous transfusion, intraoperative cell salvage (ICS) especially, has been frequently reported.[2-5] However, some controversy exists about the efficacy of ICS in aortic surgery, with three randomized trials showing significant reductions in allogeneic transfusion[6-8] and one showing little benefit.[9] Other autologous transfusion techniques are less popular in vascular surgery, and acute normovolemic hemodilution (ANH) in particular is rarely used.[10,11] In a recent multicenter trial performed by our unit, the combination of ANH and ICS significantly reduced exposure to allogeneic blood during and after aortic surgery.[8] However, allogeneic blood requirements in this trial were substantial even with autologous transfusion, with significant variation among participating centers. Because we routinely use ANH and ICS, we decided to review our experience with this transfusion strategy in infrarenal aortic surgery. The aim of this work was to report allogeneic blood use in a unit with a keen interest in blood conservation strategies.

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METHODS

We have maintained a prospective database on autologous blood transfusion since 1995. This database was searched for all records on patients who underwent aortic surgery in South Manchester University Hospital under the care of a single consultant surgeon from January 1995 to February 2001. Demographics, details of surgery, and transfusion requirements were all recorded. Data collection was completed with a retrospective review of hospital records to confirm patient characteristics and clinical outcome.

Autologous transfusion. Autologous transfusion was performed according to a standard protocol.

Acute normovolemic hemodilution. Before skin incision, sufficient blood was taken to reduce the hemoglobin concentration to 11 g/dL. The amount of blood to be removed was calculated with the following formula[12]: $(Hb - 11)/[(Hb + 11)/2] \times$ blood volume, with Hb representing hemoglobin.

Blood volume was calculated before surgery from height and weight with standard nomograms.[13] Blood was collected from central venous lines into bags containing citrate-phosphate-dextrose-adenine-1 anticoagulant, labeled according to published guidelines[12] and replaced simultaneously with a peripheral infusion of crystalloids at a 3:1 volume ratio. ANH was directed by the anesthetist, who controlled the rate of bleeding according to heart rate, arterial pressure, and electrocardiographic monitoring.

Cell salvage. Blood lost during surgery was salvaged with a centrifugal cell salvage device (Haemonetics Cell Saver 3 or 5, Haemonetics, United Kingdom; or Fresenius CATS, Fresenius, Germany), washed, and reinfused. All swabs were washed in heparinized saline solution (50

units/mL), which then was processed with the cell salvage device. Five thousand units of heparin were given routinely before aortic cross clamping and were not reversed at the end of the procedure.

Blood losses were calculated from suction reservoirs; blood lost to drapes was estimated visually by the cell salvage operator in each case. Autologous blood was always reinfused within 6 hours of collection.[12] If transfusion was needed during surgery, salvaged red cells were given first. After reinfusion of salvaged red cells, allogeneic transfusion was given only when the hemoglobin concentration fell below 8 to 8.5 g/dL or when unstable vital signs (in particular ST segment depression on electrocardiographic monitoring) persisted despite correction of hypovolemia. ANH blood was reserved for reinfusion at wound closure (after reinfusion of salvaged red cells and, if necessary, allogeneic blood transfusion) to replenish platelets and clotting factors when most needed.

Analysis of results. All data were tabulated in a computer file and analyzed with statistical software (SPSS 9, SPSS Inc, Chicago, Ill). Continuous variables were presented with medians and interquartile ranges (IQRs) and compared with the nonparametric Mann-Whitney *U* test. Proportions were compared with the χ^2 test or the Fisher exact test. Stepwise logistic regression was used to identify predictors of the need for allogeneic transfusion. Covariates in this analysis were hemoglobin concentration, platelet count, type of aortic disease (aneurysmal or occlusive), aspirin intake, and intraoperative blood loss.

RESULTS

Patients. Two hundred and twenty-one patients who underwent elective aortic surgery from January 1995 to February 2001 were identified. Of these, 111 were excluded from the analysis for the following reasons: 44 underwent complex reconstructions (suprarenal or thoracoabdominal aneurysms; replacement of aortic grafts, combined procedures); 33 were recruited in trials on different transfusion strategies; 31 underwent ICS only, because of a suspected contained rupture or low preoperative hemoglobin (precluding collection of at least 1 unit of blood according to the formula reported previously); and three cases had no medical records available for review. One hundred and ten patients underwent ANH and ICS during either aneurysm repair (n = 78) or aortobifemoral bypass for occlusive aortic disease (n = 32). Sixty men and 18 women, with a median age of 72 years (IQR, 67 to 77 years) underwent aneurysm repair, and 23 men and nine women, with a median age of 65 years (IQR, 52 to 71 years), underwent surgery for occlusive disease.

Median preoperative hemoglobin concentration was 13.8 g/dL (IQR, 12.9 to 14.8 g/dL), and platelet count was 228×10^9/L (IQR, 193 to 280×10^9/L). For patients with an aortic aneurysm, the median aneurysm size was 6.0 cm (IQR, 5.7 to 7.0 cm). Comorbidities and smoking habits were summarized in Table I. Median procedure time (including anesthetic and operating times) was 165 minutes (IQR, 135 to 210 minutes) in aneurysm repairs and 188 minutes (IQR, 170 to 240 minutes) in surgery for occlusive disease. Ten patients needed a suprarenal clamp during aneurysm repair, and only one needed one during aortobifemoral bypass for occlusive disease.

Table I. Preoperative risk factors

	AAA (*n* = 78)	*ABG* (*n* = 32)
Cardiac disease	38 (49%)	7 (28%)
Pulmonary disease	12 (15%)	5 (16%)
Hypertension	29 (37%)	11 (34%)
Diabetes	5 (6%)	4 (13%)
Renal impairment	3 (4%)	0
Stroke/TIAs	7 (9%)	3 (9%)
Smokers		
Never	13 (17%)	4 (12%)
Former	25 (32%)	14 (44%)
Current	52 (50%)	14 (44%)

AAA, aneurysm repair; *ABG*, aortobifemoral bypass; *TIA*, transient ischemic attack.

Blood volumes. The median blood volume was 4840 mL (IQR, 4097 to 5180 mL) in patients who underwent aneurysm repair and 4699 mL (IQR, 3573 to 4981 mL) in those who underwent aortobifemoral bypass for occlusive disease. Before skin incision, 1 to 4 units of blood were collected from each patient during ANH. Blood losses and salvaged red cell volumes were significantly lower in patients who underwent aortobifemoral bypass for occlusive disease (Table II). Allogeneic blood was not necessitated in 74 cases (67%), with only 115 units transfused to 36 patients (33%; Table II). Of these, 29 had aneurysms and seven had occlusive aortic disease ($P = .18$); the overall median transfusion requirement was 0 units (IQR, 0 to 2 units). Only four patients, all undergoing aneurysm repair, needed more than 5 units of stored blood. There appeared to be a learning effect because the last 61 consecutive patients completely avoided stored blood transfusion during surgery. Logistic regression identified only two protective factors against stored blood transfusion: high preoperative hemoglobin (odds ratio, 0.5; 95% confidence interval, 0.35 to 0.84 for a 1 g/dL increase; $P = .006$) and high platelet count (odds ratio, 0.6; 95% confidence interval, 0.41 to 0.94 for a 50×10^9/L increase; $P = .023$). Blood loss, aspirin intake, or type of aortic disease (aneurysm or occlusive) did not predict the need for allogeneic transfusion in our patients. Transfusion of other blood products was uncommon: 5 units of platelets were necessary in two cases, and four patients needed a total of 21 units of fresh frozen plasma. Postoperative outcome is summarized in Table III. Unsurprisingly, the 11 patients needing further surgery had large allogeneic blood requirements: 3 units (0 to 6 units) compared with 0 units (0 to 1 units) when reoperation was not necessary ($P < .001$). Furthermore, the 65 patients with uneventful postoperative recoveries only needed a total of 33 units. On discharge, the median hemoglobin concentration was 11.4 g/dL (IQR, 10.4 to 12.3 g/dL) and the platelet count was 291×10^9/L (IQR, 212 to 388×10^9/L). The median hemoglobin concen-

Table II. Blood losses, salvaged red cell volumes, and transfusion requirements

	AAA (n = 78)	*ABG (n = 32)*	P *value*
Blood loss (mL)*	1140 (683-1609)	775 (400-1225)	.02
Salvaged red cells (mL)*	403 (256-563)	250 (200-290)	.001
Patients transfused (no.)	29	7	.18
Transfusion requirements (units)*	0 (0-2)	0 (0-0)	.09

*Median (IQR).
AAA, Aneurysm repair; *ABG*, aortobifemoral bypass.

Table III. Outcome of surgery

	AAA (n = 78)	*ABG (n = 32)*	P *value*
Complications	33 (42%)	12 (37%)	.8
MI/LVF/arrhythmia	15 (19%)	3 (9%)	
Chest "infection"	14 (23%)	1 (3%)	
Respiratory failure	4 (5%)	1 (3%)	
Hemorrhage	3 (4%)	1 (3%)	
Renal failure	7 (9%)	0	
Bowel obstruction/perforation	2 (3%)	1 (3%)	
Limb ischemia	2 (3%)	2 (6%)	
Miscellaneous*	7 (9%)	5 (16%)	
Reoperations	7 (9%)	4 (12%)	.83
Hemorrhage	3 (4%)	1 (3%)	
Limb ischemia	2 (3%)	2 (6%)	
Bowel obstruction/perforation	2 (3%)	1 (3%)	
Deaths	7 (9%)	2 (6%)	.43
MI	5 (6%)	2 (6%)	
Multiorgan failure	2 (3%)		
Postoperative stay (days)†	9 (8-13)	8 (7-11)	.09

*Includes four wound hematomas, one wound infection, two minor strokes, two deep vein thromboses, and three urinary retentions.
†Median (IQR).
AAA, Aneurysm repair; *ABG*, aortobifemoral bypass; *MI*, myocardial infarction; *LVF*, left ventricular failure.

tration was 11.6 g/dL (IQR, 10.3 to 12.7 g/dL) in patients with allogeneic blood transfusion and 11.4 g/dL (IQR, 10.4 to 12.2 g/dL) in those avoiding transfusion ($P = .74$).

DISCUSSION

We described the largest reported series of aortic reconstructions with an autologous transfusion strategy consisting of ANH and ICS. Transfusion requirements were virtually limited to patients with complications, with 40% of stored blood given to 11 patients needing second operations. Some transfusions could have been given in violation of our transfusion trigger, as shown by a relatively high hemoglobin concentration in transfused patients on discharge. Because our study was retrospective, identification of the number of inappropriate transfusions was impossible.

Our results compare well with previously published series in which stored blood was given to 96% of cases without autologous transfusion[7] and 66% of cases when ICS was used alone.[9] Although the combination of ANH and ICS was important, we used a restrictive transfusion trigger, a hemoglobin concentration of 8 to 8.5 g/dL, which has been adopted in more recent literature.[14-16] Furthermore, blood loss measurements were lower than previously reported.[6,17,18] In this series, transfusion requirements were lower than those reported by the recent Autologous Transfusion in Surgery trial,[8] which used the same autologous transfusion strategy and similar transfusion triggers. In this randomized trial (in which our unit participated), 43% of the "autologous" patients needed allogeneic blood. Our comparatively contained allogeneic transfusion requirements could be the result of attention to operative blood loss and longer experience with autologous transfusion techniques. Because intraoperative allogeneic transfusion was rarely necessitated, and not necessitated at all in the last 61 patients, we no longer crossmatch allogeneic blood before elective infrarenal aortic surgery, whether for aneurysm repair or aortobifemoral bypass. Before surgery, a blood sample is analyzed for blood grouping and screened for atypical antibodies in all patients. If allogeneic blood is needed, blood then can be rapidly crossmatched and transfused within 10 to 15 minutes of request, unless atypical antibodies are present. In practice, we have not had delays in transfusing allogeneic blood when this was necessary.

Because all patients underwent ANH and ICS, conclusions about the safety of our transfusion strategy are not possible. In the recent Autologous Transfusion in Surgery trial, however, no evidence was seen of increased morbidity or mortality rates with ANH and ICS.[8] A mortality rate of 8% for elective aortic surgery is in line with large multi-

center reviews from the United Kingdom and United States.[19,20] Furthermore, some of our patients were referred by other vascular surgeons from peripheral hospitals in view of their preoperative risk, and 10% needed suprarenal clamping. Recent reports, however, have shown a low mortality rate even in patients at high risk and in the elderly.[21] Our restrictive transfusion trigger possibly may have contributed, in some cases, to the development of cardiac complications, which occurred in nearly one fifth of our aneurysm repairs and caused more than three quarters of our deaths. Only a large study comparing liberal and restrictive transfusion triggers in aortic surgery, however, would be able to provide a definite answer to this question.

The efficacy of ANH in blood conservation strategies has been disputed, mainly on the basis of mathematic modeling showing only modest reduction in net hemoglobin losses.[22] These models fail to reflect clinical practice, as ANH blood was reinfused immediately after bleeding started during surgery. The obvious mechanism by which ANH reduces transfusion requirements is dilution of intraoperative blood losses. When ANH is used in combination with ICS, intraoperative blood loss is replaced with salvaged red cells, effectively prolonging the hemodilution period. Furthermore, delaying reinfusion of ANH blood until wound closure may provide fresh platelets and clotting factors when hemostasis is most necessary. Evidence exists that hemodilution associated with bleeding produces a relative hypercoagulability, which may reduce further bleeding.[23] In this study, differentiation of the effect of ANH from that of ICS was impossible because all patients underwent both procedures. A recently published randomized trial does, however, suggest that ANH significantly contributes to reduce allogeneic transfusion in aortic aneurysm repair.[24] Aortobifemoral bypasses were associated with significantly lower blood losses, yielding smaller volumes of salvaged red cells, which did not justify routine cell salvage. Our current practice is to use ANH alone for aortobifemoral bypass in patients with normal preoperative hemoglobin.

The lack of a control group and the retrospective nature of this study clearly limit the weight of our conclusions. However, these results show that the combination of autologous transfusion with restrictive transfusion triggers and careful surgery render allogeneic blood transfusion largely unnecessary during infrarenal aortic surgery. Postoperative transfusion is still necessitated in some patients, particularly those with complications. Further randomized trials now are needed to separately evaluate ANH and ICS as part of a coherent transfusion strategy in moderate and high blood loss surgery.

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